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Hydrochemical processes in the alluvial aquifer of the Gwydir River (northern New South Wales, Australia)

Anna Menció[a,b,*], Josep Mas-Pla[a], Kathryn Korbel[c], Grant C. Hose[b]

[a]*Grup de Geologia Aplicada i Ambiental (GAiA), Centre de Geologia i Cartografia Ambientals (GEOCAMB), and Àrea de Geodinàmica, Departament de Ciències Ambientals, Universitat de Girona, Campus de Montilivi, 17071 Girona, Spain.*
[b]*Department of Biological Sciences and Environment and Geography, Macquarie University, NSW 2109, Australia*
[c]*School of Environmental Sciences, University of Technology Sydney, PO Box 123, Broadway, Sydney, NSW 2007, Australia*

Abstract

The hydrochemistry of the Narrabri Formation, the shallow aquifer system of the alluvial fan of the Gwydir River (NSW, Australia), is analyzed to better understand the hydrogeological processes involved in aquifer recharge, and to set up future management options that preserve the quantity and quality of water resources. Results show that groundwater hydrochemistry in this alluvial aquifer is mainly controlled by silicate weathering and cation exchange. However, salt remobilization in specific sedimentary layers within this alluvial fan deposit may locally increase groundwater salinity. Mixing between stream leakage and aquifer groundwater controls the hydrochemistry of water resources and produces a decrease in its salinity, which is beneficial for human uses.

Keywords: alluvial aquifer, sodium, hydrochemistry, Gwydir River .

1. Introduction

The Gwydir River is located in a semiarid region with a mean annual rainfall of 583 mm, and average minimum and maximum temperatures of 5 and 33 ºC, respectively. It lays in one of the primary cotton growing areas in Australia. It is the major tributary of the Barwon-Darling river system, and drains a portion of the Great Dividing Range (northern New South Wales). This basin contains an alluvial fan located in the Lower Gwydir Valley, which is divided into two main aquifer systems: a shallow aquifer system (10-30 m depth from the surface); and a deep aquifer (35-80 m). The shallow, generally unconfined, coarse gravel aquifer system is locally known as the Narrabri Formation. This aquifer is

* Corresponding author. Tel.: +34-972-418704; fax: +34-972-41 8150.
E-mail address: anna.mencio@udg.edu.

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separated from the deeper and confined/leaky aquifer system, the Gunnedah Formation, by a thick, low-permeability layer of clay.

Barrett [1] proposed that the dominant recharge process for the Narrabri Formation is leakage from rivers and watercourses. Additional recharge is also expected from rainfall, weir pools, on-farm storages, irrigation losses and groundwater inflows from the east.

These two aquifers have been exploited for more than 30 years for urban and agriculture purposes, causing significant changes in groundwater flow directions. For instance, large drawdowns and recovery decline occur in the Narrabri Formation to the north of the Gwydir River, where the majority of extractions occur. In addition, groundwater usage from the deep aquifer has induced downwards leakage from the shallow aquifer, causing a decline in water levels in the shallow aquifers and reversal in hydraulic gradient in some wells [1].

In this context, a hydrochemical analysis of the shallow aquifer water has been conducted to better understand the hydrogeological processes involved in the aquifer recharge, as a means to explain its groundwater variability and set up future management options that preserve the quantity and quality of water resources and avoid undesirable effects on the stream-aquifer relationship.

2. Methods

Groundwater samples were taken in 20 wells, located on the alluvial floodplains of the Gwydir River, during four sampling campaigns (August 2007, February 2008, February 2010 and August 2010). The final number of samples for each field campaign was 20, 16, 15 and 9, respectively.

Physicochemical parameters, such as dissolved oxygen, electrical conductivity, pH and temperature were measured in situ. Water samples, collected after the bore was completely purged, were refrigerated, and transported to laboratories within 14 days of collection. Laboratory analysis was performed at NSW Office of Water Analytical Laboratory in Arncliffe, Sydney. Samples were analyzed for major ions. Surface water data was obtained from [2]. The quality of the chemical analysis was checked performing an ionic mass balance; all errors were lower than +/- 5%.

3. Results and discussion

According to their hydrochemistry, Narrabri Formation groundwater samples are classified as follows:

- *Group 1*: Na-HCO_3 facies, the wells in this group are located across the whole studied area at a certain distance from the main streams, and in some cases close to the distant alluvial aquifer boundaries. Their groundwater origin is attributed to direct infiltration from rainfall or to groundwater inflows from the eastern ranges. These samples define the alluvial aquifer groundwater signature.
- *Group 2*: Na-Ca-Mg-HCO_3 facies, these samples include surface water from the Gwydir River, as well as groundwater samples affected by stream leakage.
- *Group 3*: Na-Cl facies, mainly represented by samples of a single well located close to the northern alluvial fan limit, in the central part of the basin. This well had the highest EC values, ranging from 5,080 to 5,690 μS/cm, with high concentrations of Na^+ and Cl^-, but also of Ca^{2+}, Mg^{2+} and HCO_3^- as well. It is not influenced by stream water recharge. Groundwater with similar characteristics has also been described in the western part of the Border Rivers Catchment, and its origin was attributed to evaporation, remobilization of salts and cation exchange processes associated with lithological heterogeneities of these alluvial fan deposits [3]. Some samples also suggest a mixing between this end-member and other groundwater types.

The hydrochemical evolution of samples of Groups 1 and 3 is clearly different. In Figures 1a and 1b, samples of Group 3 (square symbols) are situated close to the relation 1:1 for Ca^{2+} and HCO_3^-, and for Na^+ and Cl^-. Although distinct EC values are detected within this group of samples, they maintain the ionic ratios, due to water-rock interaction processes such as mineral dissolution and salt remobilization; while samples of Group 1 (triangle symbols) show a Ca^{2+} depletion relative to HCO_3^-, and an approximate Cl^-:Na^+ ratio of 1:3; meaning that additional processes affect Ca^{2+} and Na^+ concentrations. In this sense, the main minerals that could release Na^+ in this kind of sedimentary aquifer are K-feldspars and albite in their incongruent dissolution. Their weathering can be described as follows [4]:

- Incongruent dissolution of K-feldspar (sanidine) to kaolinite:
  $(Na,K)\,AlSi_3O_8 + 2CO_2 + 3H_2O <-> Al_2Si_2O_5(OH)_4 + K^+ + Na^+ + 2HCO_3^-$ (1)
- Incongruent dissolution of albite to montmorillonite:
  $3NaAlSi_3O_8 + Mg^{2+} + 4H_2O <-> 2Na_{0.5}Al_{1.5}Mg_{0.5}Si_4O_{10}(OH)_2 + 2Na^+ + H_4SiO_4$ (2)
- Incongruent dissolution of albite to kaolinite:
  $2NaAlSi_3O_8 + 2H_2CO_3 + 9H_2O <-> Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^-$ (3)

  In addition, Na^+ can be the product of cation exchange.

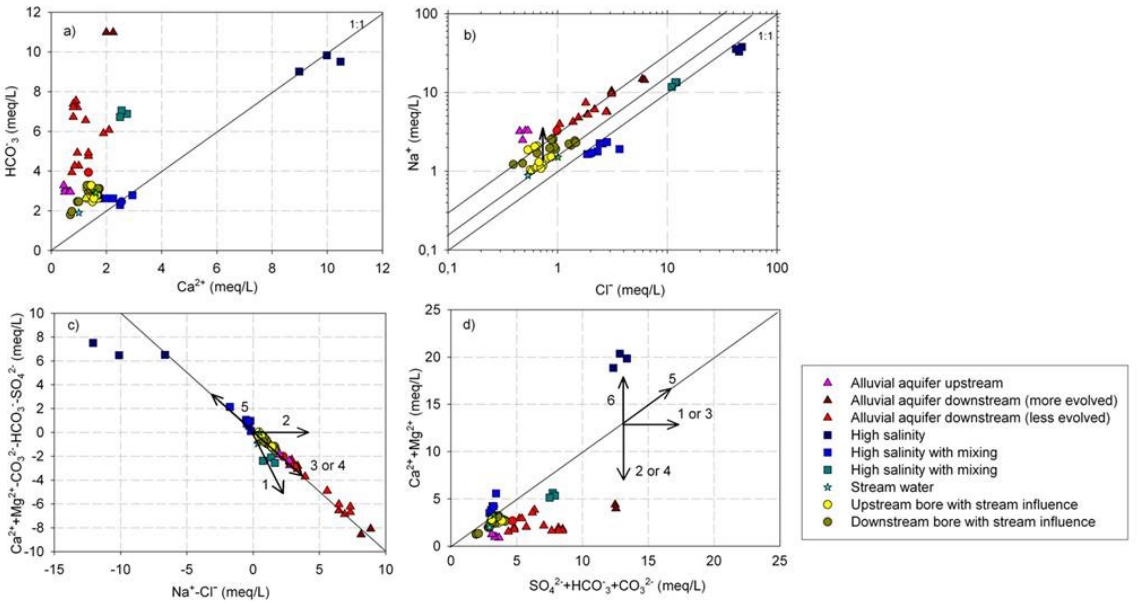

Fig. 1: a) HCO_3 v. Ca (meq/L); b) Na v. Cl (meq/L); c) Ca+Mg-CO_3-HCO_3-SO_4 v. Na-Cl (meq/L); d) Ca+Mg v. SO_4+HCO_3+CO_3. Legend: Group 1, triangles; Group 2, circles; Group 3, squares; Surface Water, stars.

Figure 1c and 1d analyzes the origin of Na^+ in groundwater through different ionic relationships, and it reflects some of the reaction processes that affect Gwydir River aquifer hydrochemistry: if incongruent dissolution of sanidine takes place, increase in Na^+ and HCO_3^- lays on a 1:2 relation, but it does not affect Ca^{2+} and Mg^{2+} concentrations, following reaction path 1; if incongruent dissolution of albite to montmorillonite occurs, an increase in Na^+, but not in HCO_3^-, must be detected, and a decrease in Mg^{2+} is expected as well, according to reaction path 2; if incongruent dissolution of albite to kaolinite happens,

the relation between Na^+ and HCO_3^- must be 1:1, following the reaction path 3; if cation exchange takes place, the reaction path followed should be 4, due to the release of Ca^{2+} and increase of Na^+; however, if inverse cation exchange occurs, an increase in Ca^{2+} and a decrease in Na^+ will be expected, following reaction path 5; and finally, if remobilization of salts happens, samples shouldn't move from their original point in Figure 1c and due to the homogenous increase in both anions and cations, the reaction path followed should be 6 in Figure 1d.

In the study area, samples of Group 1 seem to be affected by incongruent dissolution of albite to kaolinite, because they follow the reaction path 3 in the Figure 1c and d. However, an usual reaction couple as cation exchange and calcite dissolution, will decrease Ca^{2+} and increase HCO_3^- contents, and result in the same reaction path (e.g. [4], [5]; Figure 1a), but calcite dissolution is not expected to be a leading reaction in this aquifer. Nevertheless, samples of group 3 follow reaction path 5 in Figure 1c and 5+6 in Figure 1d, confirming that they are affected by both processes, inverse cation exchange and remobilization of salts, thus resulting in higher salinity waters as shown in Figures 1a and 1b.

In addition, samples affected by stream leakage located both upstream, and downstream (yellow and dark yellow circles in Figure 1) do not seem to be affected by any other process than mixing with surface waters (turquoise stars) and aquifer groundwater. These samples are characterized by lower EC values. Consequently, natural or induced stream water leakage has a positive effect by controlling and reducing the primary salinity of the aquifer related to silicate weathering through water-rock interaction.

4. Conclusions

The analysis of hydrochemical data allows us to distinguish different hydrochemical processes that affect groundwater in the Narrabri Formation, and its quality. Groundwater hydrochemistry in this alluvial aquifer is mainly controlled by silicate weathering and cation exchange. Salt remobilization in specific sedimentary layers within this alluvial fan aquifer locally increases groundwater salinity. Mixing of stream leakage with aquifer groundwater controls the hydrochemistry of water resources and produces a decrease in its salinity, making it suitable for human uses.

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